

An Electromagnetic Articulography study of resyllabification of rhotic consonants in English.

Richard Mullooly

Queen Margaret University College, Edinburgh

E-mail: Rmullooly@QMUC.ac.uk

ABSTRACT

Recent instrumental work has focused on finding phonetic correlates of intervocalic consonants' syllabic affiliation. The importance of lexical stress as a determining factor word internally has either been acknowledged [1], or suggested [2]. There is much work in word internal contexts, but limited work across word boundaries. I examined word final intervocalic [ɹ] in non-rhotic English speech, with Electro-magnetic Articulography (EMA) using *car out* and *peer out* for stimuli, varying the emphatic stress environment. For two speakers, the lingual articulators moved more rapidly in the transition from word final [ɹ] to the following vowel when the word following <ɹ> was stressed. A Scottish rhotic speaker showed the same effect. The higher velocity suggests the consonant is more likely to be parsed as a syllable onset. I argue emphatic stress increases tension which accounts for the low velocity observed in tokens where the first word was stressed and that the stiffness parameter (*k*) of Articulatory Phonology is related to bio-mechanical stiffness.

1. INTRODUCTION

Ambisyllabicity and the syllabic affiliation of intervocalic consonants have attracted theoretical interest in instrumental literature in recent years [3], [2]. In a generative phonology framework, Kahn [4] argues stress affects the syllabic affiliation of intervocalic consonants word internally, e.g. in a word like *pony*, the /n/ is ambisyllabic or simultaneously affiliated to both syllables if the first syllable is stressed. If the second syllable is stressed, it is an onset. Turk's X-ray microbeam study on word internal intervocalic bilabial plosives, e.g. *caliper*, showed very clearly that the alternation of the lexical stress environment (varying the syllable which was stressed) affected the closing - opening gestures of the intervocalic plosive. When the first syllable was stressed, intervocalic consonants' gestures patterned with unequivocal syllable final plosives, e.g. the /p/ in *microscope*. When the second syllable was stressed the gestures resembled those of syllable initial plosives, e.g. the /p/ in *pony*.

Similarly to the results of Turk's X-ray study, Nolan's (Electropalatographic) EPG - acoustic study on word

internal intervocalic plosives (*tucker*, *tucking*, *ticker* and *ticking*) in words whose first syllable was stressed showed the influence of the first stressed vowel on the velar [3]. Anterior lingual-palatal contact was observed in *ticker* and *ticking* but contact was further back in the vocal tract for *tucker* and *tucking*. Though Nolan's acoustic data was not in line with his articulatory data in that they showed the second vowel's influence on the velars' acoustic characteristics, the influence of the stressed vowel on the consonants' place of articulation was clear.

There is very limited work on intervocalic consonants across word boundaries, though Krakow examined bilabial nasals in this context. She compared word initial and word final bilabial nasals in nearly homophonous phrases (e.g. *see more* vs. *seam ore*) and found that varying the stressed syllable affects the magnitude and duration of nasals' gestures [3]. Bilabial nasals indicated orthographically in stressed syllables showed longer velum lowering and greater velum and labial articulatory displacement. It is interesting to note that Kahn's argumentation suggests that stress is irrelevant to intervocalic consonants' language specific phonetic detail across the word boundary. 'Ambisyllabicity' is the term he uses in his phonological modeling of intervocalic consonants' allophonic traits. In American dialects which have syllable onset aspirated /t/, flapped /t/ in intervocalic position across the word boundary and glottalised /t/ in coda position, the ambisyllabic intervocalic /t/ is flapped whichever syllable is stressed. If it did resyllabify when the following syllable and word was stressed it would be aspirated.

Given that stress has been shown to affect the articulation of intervocalic consonants word internally and across word boundaries, it should not perhaps be too surprising that in Browman and Goldstein's Articulatory Phonology model stress can modify the parameters of the tract variable goal to be achieved and stiffness (*k*). In the following discussion I focus on the stiffness parameter when referring to Articulatory Phonology. This approximately specifies the time required to achieve a target. The possibility has been raised that there may be a relationship between the stiffness parameter and bio-mechanical stiffness [5], [6].

2 METHODOLOGY

Three non-rhotic subjects all male in their late teens to mid twenties were recruited after acoustic and auditory

analysis of monologue speech and a reading list of sentences with orthographic <r> in different contexts, word initial, word final intervocalic and word final. The reading list also included ‘intrusive [ɹ]’ sites where no orthographic <r> is indicated, but an [ɹ] sound can be produced intervocalically, e.g. *saw[ɹ] eels*. Subjects were classed ‘non-rhotic’ only if they produced word initial and word final intervocalic [ɹ] (indicated orthographically and intrusive), but did not show acoustic or auditory evidence of an [ɹ] sound in word final position, i.e. if there was no low F3 in the last context. A nineteen year old male rhotic speaker who had a low F3 in word final coda context and no tokens of ‘intrusive [ɹ]’ was also recruited. All three non-rhotics JG, GS and SS, and the rhotic MJ were phonetically untrained.

Stimuli consisted of two phrases with word final intervocalic <r>. These were *car out* and *peer out*. In order to vary the emphatic stress environment (alter the syllable which was stressed), the stimuli were placed in a carrier phrase following a similar two word phrase with a different semantically related word to one in the stimuli. For example, to obtain stress on the word *out* in the stimuli, the phrases used were: ‘I didn’t say *car* **in** I said *car out*’ and ‘I didn’t say *peer* **in** I said *peer out*’. In order to place stress on the first word I used the phrases ‘I didn’t say **bus** out, I said **car** out’ and ‘I didn’t say **look** out, I said **peer** out’. Thirty-six tokens of both phrases (eighteen per stress environment) were collected.

The facility I used for articulatory analysis was Carstens Electromagnetic Articulograph (EMA). It is a tracking device that records the movement of articulators via the attachment of electronic receiver coils. Voltages are induced in the receivers by three fixed electromagnets whose points of situation (at the subject’s chin, top of the head and behind the neck) form an equilateral triangle surrounding the mid-sagittal plane. These voltages are used to establish the location of coils in the mid-sagittal plane. Movement data is sampled at 500hz. Tangential velocity can also be recorded. It is this data that was used in the experiment in which I measured the maximum speed of the lower lip, tongue tip and tongue dorsum in the transition out of the [ɹ] into the following vowel in both stress environments for the phrases *car out* and *peer out*. The movement data and acoustic data are temporally aligned with reference to laryngograph readings. Figure one below, a token of *peer out* shows how the measurements were taken for velocity data.

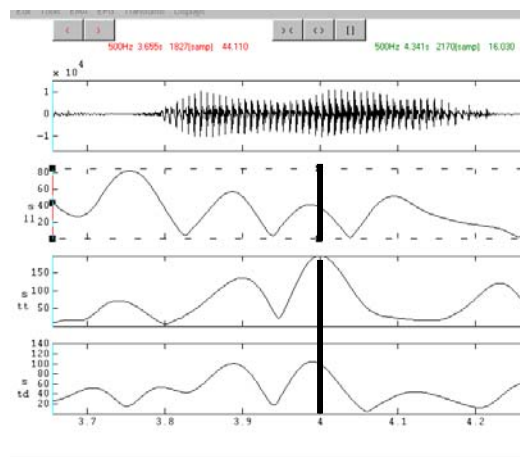


Figure 1. EMA tangential velocity data

The top track in figure one shows laryngograph data. The other three tracks show the tangential velocity of the lower lip (ll) tongue tip (tt) and tongue dorsum (td). Velocity of articulators is shown in the vertical axis of each track. Articulators’ speed decreases to a minimum as they reach their target position for a speech sound. The low points in the track indicate points in time where an articulator is moving the least and where it is assumed to have reached its target position for a given speech sound. In all tokens there were extremely clear points where the articulators had reached their target position for the [ɹ] (speed minima). The speed increases in transitions from one speech sound to another. The vertical line through each of the three tracks at the point of high velocity of the articulators indicates the times of the maximum tangential velocity of the lower lip, tongue tip and dorsum in the transition from [ɹ] into the diphthong of *out*. The velocity values were measured at this point in time in the experiment. Standard two-tailed t-tests were always used for statistical analysis.

3 RESULTS

In the non-rhotic data, both the tongue tip and tongue dorsum showed a systematic trend to reach higher velocities if sentences were read with the second word stressed.

Figure two below shows the mean tip values for JG in the phrases *peer out* (on the left) and *car out* (right) with standard deviations. In both cases, the mean where the first word is stressed is shown in black, and white where the second word *out* is stressed.

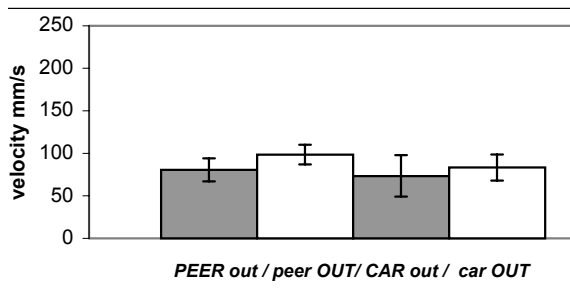


Figure 2. Mean max TT velocity (JG)

The chart shows a tendency for the tip to reach a higher speed when the second word *out* is stressed. Findings were significant for the phrase *peer out* ($p < 0.0002$) but not *car out* ($p < 0.15$). The tongue tip also moved more quickly for speaker GS when the second word was stressed. Figure four below shows the means for his maximum tongue tip velocity for both phrases with standard deviations.

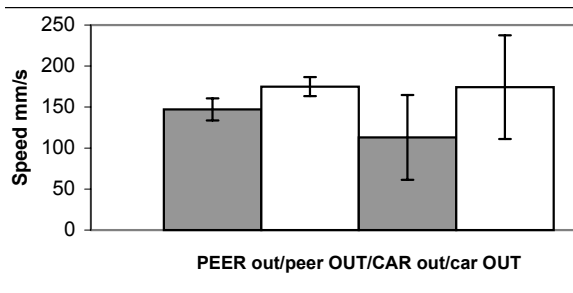


Figure 3. Mean max TT velocity (GS)

In this speaker's case the tendency for the tip to move quicker was clear in both phrases. Both T- tests were significant ($p < 0.0002$ *peer out*, $p < 0.005$ *car out*).

Findings for the tongue dorsum reflected findings for the tip. Figure four below shows the mean maximum speed of the dorsum in the transition from [ɹ] to following vowel for speaker JG with standard deviations.

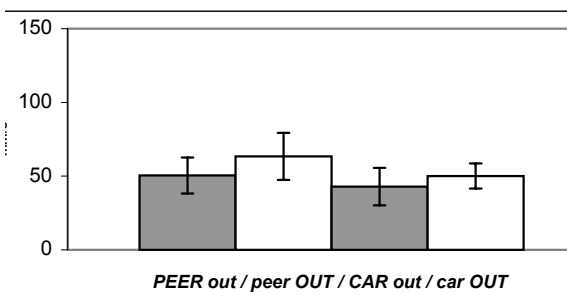


Figure 4. Mean max TD velocity (JG)

T-tests were significant for *peer out* ($p < 0.02$), but not for *car out* ($p < 0.2$). Greater levels of significance were

observed however for speaker GS. Figure five shows his tongue dorsum means.

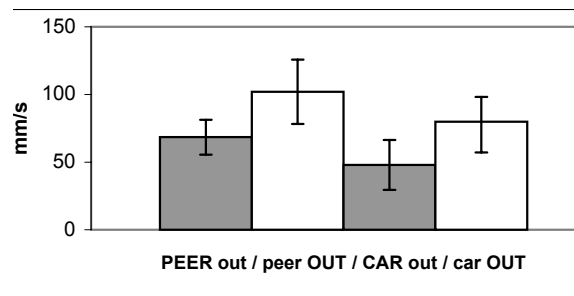


Figure 5. Mean max TD velocity (GS)

T-tests on the dorsum were highly significant for both phrases ($p < 0.00002$ *peer out*, $p < 0.0001$ *car out*), showing that the dorsum was clearly affected by the stress environment in this context for this speaker. Results were all insignificant for the third non-rhotic speaker SS.

The effect may not be limited to non-rhotic dialects. Data was also analysed from the Scottish rhotic speaker, who pronounced the word final /ɹ/ of *peer out* with an alveolar tap. The same effect was observed for both phrases in his data. Tangential velocity of the coil placed on the tongue body (10 mm behind the tip coil) was measured for both phrases. A tap is produced by the ballistic motion of the tongue which makes contact with the hard palate. A consequence of the ballistic motion is the high velocity of the lingual articulator whichever syllable is stressed. However, the data analysed from the rhotic speaker showed that the lingual articulator reached a higher velocity when *out* was stressed for both phrases. This reflects findings from non-rhotic speakers. Figure six below shows the mean velocity of the tongue body (TB) for all four contexts (both phrases with the two stress environments).

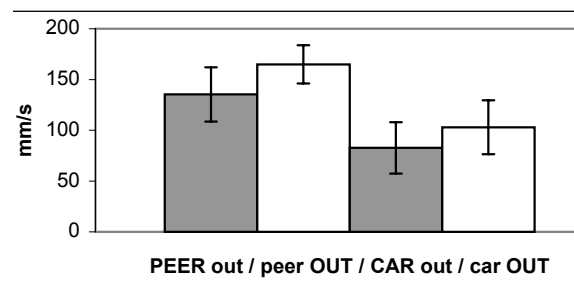


Figure 6. Mean max TB velocity (MJ)

Two tailed t-tests on both phrases reached significance ($p < 0.0007$ *peer out* $p < 0.03$ *car out*).

Alternation of the stress environment also affects *acceleration* of articulators. Two-tailed T-tests for acceleration were carried out on all contexts for the tip and dorsum where speed was affected in non-rhotic speech.

All reached significance in the predicted direction (Acceleration was always greater if out was stressed). Results are shown here (TT = Tongue Tip, TD = Tongue Dorsum): JG *peer out* (TT) $p < 0.007$, JG *peer out* (TD) $p < 0.04$, GS *peer out* (TT) $p < 0.04$, GS *peer out* (TD) $p < 0.00000008$, GS *car out* (TT) $p < 0.045$, GS *car out* (TD) $p < 0.0007$.

4. DISCUSSION

Variation of the stress environment clearly affected the velocity and acceleration of the lingual articulators for speakers JG and GS and velocity for a rhotic speaker MJ. However, the third non-rhotic speaker, SS, did not show any difference across sets. Nonetheless, a clear effect was observed for three of four speakers.

The tendency for the lingual articulators to reach high velocities when the second word is stressed is clear, but it is not a categorical effect, in that even if the first word is stressed there are some tokens in which the lingual articulators do reach high velocities. There are also cases where the second word is stressed where the lingual articulators do not achieve great speed. This is probably because what I have observed is not a rule based process involving the resyllabification of the consonant to the following onset, though the observed effect resembles grammatical resyllabification rules which take place word internally. Many current phonological models would have difficulty accounting for the observed effects. This is because they do not claim that stress has an effect on the syllabic affiliation of an intervocalic consonant *across the word boundary*. It is only *word internally* that stress is a determining factor in the syllabic affiliation of an intervocalic consonant. Recall that word final intervocalic /t/ is flapped whichever word is stressed in American dialects with flapped /t/. As it is apparently not a phonological process, a more plausible explanation can be found in the probable effects of stress on the tension of the articulators. Known phonetic correlates of stress are increases in segmental duration and articulatory displacement. It is possible that placing stress on a syllable or word will increase the bio-mechanical stiffness or tension in the muscles which are used in the production of the syllable, especially the vowel because the articulators must remain in a more peripheral position for a longer period of time. This would suggest that the stiffness parameter (k) of Articulatory Phonology is related to bio-mechanical stiffness as discussed above. The data gathered suggests an inverse relationship between the two. Recall that the stiffer the spring in Articulatory Phonology's spring-mass model, the more rapid the articulatory movement is. I argue that an increase of articulatory tension or bio-mechanical stiffness slows the movement of articulators.

My results suggest that stress affects the articulation of intervocalic consonants across the word boundary in a specific way and that the word internal syllabification rules proposed by phonologists are based in articulatory

and acoustic constraints. However, this still does not provide us with the whole picture. The location of the F0 minimum has been shown to be a robust phonetic correlate of an intervocalic consonant's syllabic affiliation across the word boundary [7]. This acoustic finding is in line with an autosegmental interpretation. However, I would not be surprised to find that there is a relationship between my finding and Ladd's, that there is a phonetic explanation and that laryngeal features are not independent from supra-laryngeal articulations as Ohala argues [8]. These are all possible issues for future research.

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